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GAMMA-RAY LARGE AREA SPACE TELESCOPE (GLAST)

OPERATIONS CONCEPT DOCUMENT

March 8, 2002

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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Prepared by:

Original Signed — *03/08/02*

Dennis Small Mission Operations Manager	Date

Approved by:

Original Signed — *03/12/02*

Elizabeth Citrin GLAST Project Manager	Date

Concurrence:

Original Signed — *03/12/02*

Jonathan Ormes GLAST Project Scientist	Date

Original Signed — *03/10/02*

Peter Michelson Large Area Telescope Principal Investigator	Date

Original Signed — *03/08/02*

Charles Meegan GLAST Burst Monitor Principal Investigator	Date

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ACRONYM LIST

ACD	Anticoincidence Detector
CHK	Continuous housekeeping data type
CCSDS	Committee for Space Data Systems
CSPEC	Continuous high energy resolution data type
CTIME	Continuous high time resolution data type
DPU	Data Processing Unit
GBM	GLAST Burst Monitor
GCN	GRB (Gamma Ray Burst) Coordinates Network
GeV	Billion Electron Volts
GLAST	Gamma-ray Large Area Space Telescope
GN	Ground Network
GOF	Guest Observer Facility
GPS	Global Positioning System
GS	Ground Station
HEASARC	High Energy Astrophysics Science Archive Research Center
IOC	Instrument Operations Center
kbps	thousand bits per second
km	kilometer
LAT	Large Area Telescope
LAT DPF	Large Area Telescope Data Processing Facility
Mbyte	Million Bytes
MeV	Million electron Volts
MOC	Mission Operations Center
NRA	NASA Research Announcement
PMT	Photo Multiplier Tube
SAA	South Atlantic Anomaly
SSC	Science Support Center
SSR	Solid State Recorder
TB	10^{12} Bytes
TBD	To Be Determined
TBR	To Be Resolved
TDRSS	Tracking and Data Relay Satellite System
TOO	Target of Opportunity
TRIGDAT	Trigger data type
TTE	Time-tagged Event

1 Introduction

The Gamma–ray Large Area Space Telescope (GLAST) is a space science mission that will launch in 2006. The GLAST science instruments are the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM). The LAT is a wide field of view detector of gamma rays in the 20 MeV to 300 GeV range. The GBM extends the energy range of burst observations from the bottom of the LAT energy range down to a few keV. This allows bursts observed with GLAST to be placed into the context of the large database of previous burst observations. The GBM will also provide an on-board trigger and approximate location for bursts that lie outside the field of view of the LAT. The primary ground station used for the GLAST mission will be located in Malindi, Kenya. A backup ground station will be used in lieu of data transmission difficulties at the primary ground station site.

1.1 REFERENCE DOCUMENTS

The following documents were referenced during the development of this document. The reader is encouraged to use current versions of these documents for further research.

- "GLAST Science Requirements Document", 433-SRD-0001
- "GLAST Mission System Specification Document", 433-SPEC-0001
- "GLAST Spacecraft Performance Specification", 433-SPEC-0003.
- "GLAST Gamma–ray Burst Monitor (GBM) Instrument – Spacecraft Interface Requirements Document", 433-IRD-002
- "GLAST Large Area Telescope (LAT) Instrument – Spacecraft Interface Requirements Document", 433-IRD-002
- "GLAST Project Data Management Plan", 433-PLAN-0009

2 Assumptions

The mission lifetime is 5 years with a goal of 10 years. The launch date is in March 2006. The orbit is 550 km circular orbit, inclined at 28.5°.

The LAT will generate an average data rate of 300 kbps. The GBM data rate will vary based on the number of bursts detected; the average rate over an orbit is 12 kbps. The instruments will detect a gamma ray burst or other transient phenomenon every day or two. Information associated with the position of the event must be communicated to the ground within a few seconds. The LAT will receive information from the GBM when the GBM detects a burst. The GBM is simple and requires no complex planning, scheduling, or commanding for routine operation.

The appendix, Observatory System Modes defines the operational modes associated with the spacecraft and instruments.

3 Reference Architecture

Figure 1 shows the reference architecture used in this operations concept.

The Mission Operations Center (MOC) is responsible for the health and safety of the mission. It coordinates the space/ground contacts with the ground station network and TDRSS, generates commands, monitors the spacecraft telemetry and critical safety parameters from the instrument engineering data, and monitors the performance of the spacecraft. The Mission Operations Center receives the spacecraft, GBM and LAT data from Malindi Ground Station. The MOC then removes the artifacts of the space-to-ground transmission – providing duplicate data removal, time ordering, and quality annotation. The MOC distributes the GBM data to the GBM Instrument Operations Center (IOC) and LAT data to the LAT Instrument Operations Center. The Instrument Operations Centers are responsible for instrument performance. They support instrument operations planning, generate instrument calibration files from calibration data, generate standard products, and maintain data processing algorithms. The Science Support Center (SSC) plans the science observations, supports science operations decisions such as the observation of a Target of Opportunity (TOO), archives the data, distributes the data to the user community, and supports the guest observers. The SSC generates standard products on subsets of data using IOC provided algorithms/software and generates products that require information from both instruments and information from other observatories. The Gamma Ray Burst Coordinates Network (GCN) distributes alerts of gamma ray bursts or other transients received from the MOC.

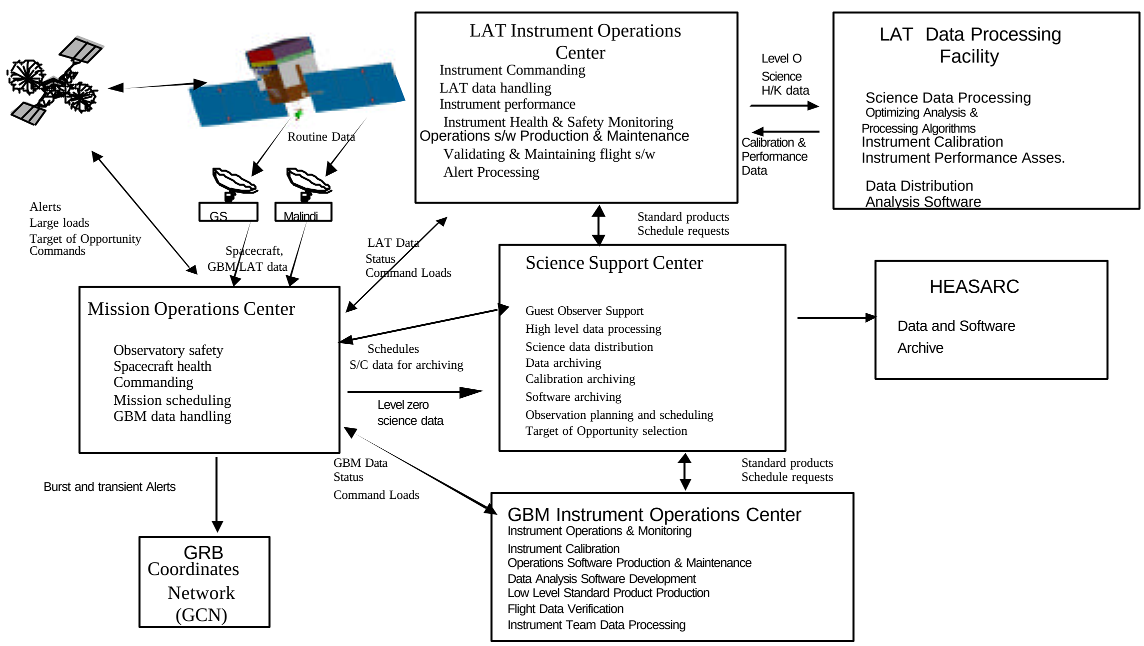

Figure 1 System Architecture

4 Operations Concepts for Routine Operations

Routine operations are those that occur during the mission after initial on-orbit checkout.

4.1 Planning

The Science Support Center will plan the GLAST observations. During first year following on-orbit commissioning, the observatory will operate primarily in Sky Survey Mode. In Sky Survey Mode, the SSC will monitor the sky coverage and may request modifications to the spacecraft motion to achieve optimal scientific return. During subsequent years guest observers will propose observations. Specific targets may also include secondary targets to be observed during earth occultation of a primary target. The SSC works with the project scientist to schedule science activities. The SSC will have planning tools to evaluate the operational plan for earth occultation and other factors. The project scientist may also access these tools to evaluate potential targets of opportunity. The SSC will plan observing programs to optimize the science observing efficiency.

The SSC will typically plan routine operations weeks to months in advance. The number of activities will be small. Targets of opportunity (TOO) are requests from the project scientist (or some designee in the SSC) to reposition the observatory for a phenomenon of interest, such as an Active Galactic Nucleus flare. The SSC will submit the request for the observation to the MOC. The MOC prepares the request for uplink, schedules TDRS, uplinks the request and notifies the SSC. The decision to observe a target of opportunity will be made by the Project Scientist or his/her designee. The SSC shall assist Guest Observers in scheduling observations and in using the data.

The IOCs will plan instrument loads and any special instrument activities. Special LAT activities could include disabling the onboard background rejection software for a short period of time, or special calibration targets. Special instrument activities that interrupt normal operations should be infrequent. The IOC-requested instrument activities will be submitted via the SSC.

4.2 Scheduling

The GLAST Observatory will playback data via the ground stations at 15 Mbps (TBR). This will require a minimum of 5 contacts per day. The MOC will schedule appropriate contacts with the ground stations for playback and with TDRSS for memory loads. The normal contact schedule will be flexible, to allow some leeway in the specific time and station used. Onboard storage will have the capacity to store at least 36 hours of data. The contacts will be scheduled during the day shift if possible, so that if a problem occurs with the downlink, or if a problem is detected with the spacecraft, the MOC operators are more likely to be immediately available to address the problem. The MOC will be capable of scheduling attitude maneuver to a more convenient orientation or to survey operation during the earth occultation.

4.3 Commanding

The spacecraft will be commanded from the ground to configure the spacecraft and instruments, initiate the downlink of data, and uplink memory loads including stored commands. When commands for normal operations are required, the MOC will format the real time commands and command loads and uplink them during the daily contacts. The spacecraft has few constraints, so the checking and formatting of commands is simple and straightforward. Command uploads are expected to occur once or twice per week during normal operations. With ground contacts and a command path through the Tracking and Data Relay Satellite System (TDRSS), the GLAST architecture will accommodate more frequent commanding, as needed (e.g. during checkout).

Absolute Time Stored Commands will be used to execute the onboard schedule, conduct pointed observations and provide onboard reconfiguration such as taking appropriate protective actions prior to entry into the SAA. The GLAST spacecraft is expected to perform most of its functions autonomously, through stored commands.

Relative Time Stored Command Sequences are used for repetitive tasks. For example, The Sky Survey mode requires a set command procedure that is loaded once and not changed, unless the SSC wishes to adjust the pattern. The Pointed Observation mode requires more commanding, but changes to preplanned targets are infrequently.

The IOCs will provide load requests to the MOC. The LAT instrument loads requests will include tables of instrument parameters (for example, gain settings) and software adjustments. The IOCs will schedule the uplink of these loads via the SSC so that the MOC has only one interface for scheduling the operation of the instrument. Large software loads for the LAT or GBM will be performed through the TDRSS Single Access Service. Large uploads may be performed several times during the initial on-orbit operations, and then should occur infrequently.

4.4 Housekeeping Telemetry Processing

The spacecraft and instruments will monitor their own telemetry onboard and report unusual conditions. The spacecraft will also have the ability to monitor key instrument parameters and it will be capable of safing the instruments if required.

The ground system will receive real time telemetry housekeeping during the space/ground contact. The MOC has the option of getting continuous health and safety status data via the Demand Access Service link. The MOC will process the spacecraft and selected instrument housekeeping data automatically to identify parameters that are out of limits, incorrect configurations, or problems logged by the spacecraft processors. If the automatic system identifies a problem, it will alert a member of the operations team. Depending on the severity of the problem this notification could vary from simply displaying a message to paging an on-call operations team member.

The complete set of housekeeping data for both instruments and spacecraft is recorded onboard and played back via X-band during the contacts. This spacecraft and instrument housekeeping data will be sent to the MOC before the science data is sent. The playback housekeeping data should be received in the MOC within a few hours of receipt at the ground station.

The spacecraft housekeeping data playbacks will be automatically processed in the MOC to identify parameters that are out of limits or configurations that are different from the expected and to produce routine plots and tables used by the spacecraft engineers to evaluate the subsystems. During the prime shift, the spacecraft engineer will review the data and adjust the operations as needed. Adjustments could be to upload new parameters to the onboard systems. If an instrument anomaly is detected, the MOC engineer may perform a predefined procedure developed with the IOCs. The MOC operator will contact the instrument operation team to inform them of the progress in the resolution of the anomaly.

The IOCs will process the instrument data. The instrument teams will use this data to assess the performance of the instrument and to adjust the instrument tables, calibration, or software as required.

4.5 Orbit Determination

The spacecraft has a GPS receiver that provides position and time information onboard. This information is sent to the ground in the housekeeping data and is also included in the science data stream. The MOC uses this data to predict the GLAST orbit and provide acquisition data to the ground station and to TDRSS.

4.6 Space/Ground Link and Communications

The data will be formatted using Consultative Committee for Space Data System (CCSDS) recommendations. The observatory will use different virtual channels for spacecraft, GBM, and LAT data. This will allow the ground station to separate the playback data. The spacecraft and GBM data and LAT data will be sent to the MOC. The playback data will be stored at the ground station for possible retransmission. The ground station will store the data for at least one week after delivery. The MOC will verify that they have received and stored the data correctly or request a retransmission. All data will use commercial communication services that provide reliable, secure, and inexpensive transfer of data using standard protocols.

The Mission Operations Center will monitor the downlink data quality as it arrives using frame status and accounting information from the ground station. If the quality is unacceptable, the Mission Operations Center may initiate the transmission of some or all of the data a second time. If time allows, this will be done during the contact; if not, the Mission Operations Center may schedule another pass with the ground station.

The space-to-ground artifacts in the data will be removed in the MOC. This will include restoring time order, duplicate data removal, and data quality annotation. This process is often referred to as level zero processing.

The GLAST has some special space/ground link requirements. When one of the instruments detects a gamma ray burst (or other transient event) 2 or 3 times per week, the ground requires notification as soon as possible so that other observatories can look at this transient event. The GLAST will use the TDRSS demand access service for these events. The Mission Operations Center will receive this message via the White Sands Complex and automatically send the alert to the GCN for distribution to interested observatories. The GBM and LAT IOCs may also provide supplementary messages to the GCN, refining the position of selected bursts. If the transient alert triggers an autonomous repointing of the instrument, information on this repointing and on the eventual reversion to the original mode (scan, pointed scan, or inertial pointing) will also be downlinked via TDRSS to the MOC to confirm spacecraft status.

A detection of a sufficiently significant burst may cause GLAST to interrupt the current operation and to point at the burst region during all non-occulted viewing time during the next 5 hours. There are two cases:

a. Burst within the LAT field of view. The LAT will request the spacecraft to interrupt the current observation mode to keep the burst within the field of view. The spacecraft may perform a maneuver to center the burst in the field of view. These bursts should happen about once per week.

b. Burst outside of the LAT field of view. The LAT will request that the spacecraft maneuver to observe the burst. These bursts should occur a few times per year.

In both cases, decisions will be based on-board using a predetermined set of criteria that assures the safety of the spacecraft. If the primary target of observation is assigned an uninterruptible priority, the current operation will continue.

In both cases, the spacecraft will keep the burst direction within 30 degrees of the LAT z-axis during at least 80% of the entire non-occulted viewing period. The spacecraft will select an orientation during earth occultations of the burst as described in section A.1.4. The spacecraft will only initiate the repointing maneuver if this operating mode has been enabled. The observation of bursts should be short compared to the duration of observations for most targets, so no rescheduling will typically be required to accommodate the interruption. The slew criteria and repointing duration will be revisited periodically throughout the mission. The spacecraft will not maneuver to a burst outside of the LAT field of view if the new orientation would interfere with an ongoing or imminent ground station contact. A ground contact is "imminent" if there is insufficient time to perform the requested repointing maneuver and then maneuver from the repoint attitude to the attitude required for the ground contact without data loss. In case of an ongoing or imminent ground contact, repointing will begin after spacecraft to ground station contact has been completed. CH-01

If a gamma ray burst is detected while the spacecraft is in contact with the ground station, the alert message will be sent over the real time link to the ground station. The MOC will forward the alert to the GCN.

Targets of opportunity are another special requirement. If some other observatory detects a phenomenon of interest, such as an Active Galactic Nucleus flare, the project scientist may decide to reorient GLAST to observe the event. The project scientist (or his designee in the SSC) will submit the request for the observation to the MOC. The MOC will verify that the requester is authorized, check the request for constraint violations, and then format a command to the GLAST spacecraft. The command will be sent using the TDRSS single or multiple access forward links. A TDRSS MA forward event will be scheduled at least 10 minutes, but not more than 120 minutes into the future based on MA or SSA forward availability. Eight seconds per degree of maneuver angle (i.e., 75 degrees in 10 minutes) are also required for spacecraft maneuvers. Targets of opportunity may occur about once per month.

4.7 Science Data Processing

The science data will be buffered onboard the spacecraft and at the ground station prior to transmission to the MOC. The data will be transmitted to the MOC for level zero processing. Once at the MOC, time is required to process the data to remove the space-to-ground artifacts and ensure correct ordering. The time to process the data depends on the implementation, but is expected to be 1 hour per 12-hour period of data. The MOC will distribute the level zero data to the SSC, LAT IOC, and GBM IOC.

There will be several data types for the LAT - event data (which makes up the bulk of the science data), calibration data, burst data, other transient data, and status data. The GBM will also have several data types – burst data, background data, and status data. The LAT event data will consist of addresses of detector hits, and information on energy deposition and Anticoincidence Detector (ACD) hits as well as the ancillary data required for processing independent of other data. The ancillary data will include mode and status information, times, spacecraft position and orientation, and whatever other information is deemed necessary for processing. In addition to instrument data, the spacecraft itself will generate engineering. The science data processing systems will be sized to have the ability to reprocess a prior days worth of data without impacting the current day of data processing.

4.7.1 LAT Data Processing

The LAT event data will be automatically subjected to analysis that determines the probability – with more sophisticated algorithms than those implemented on board - that the event is a cosmic gamma ray. The product of this process will be a searchable database of photons and cosmic rays containing, at a minimum, time, direction and energy. The science data processing at the LAT DPF will also produce other standard data products such as sky maps, gamma ray burst catalogs, and a catalog of gamma-ray point sources.

Calibration data will be analyzed and stored at the IOC and calibration parameters determined – some of which may be uplinked to the instrument to mask out 'hot' or dead detector elements. Separate database of cosmic rays may be accumulated to assist in the determination of the alignment and calibration of the detector elements. Other parameters of diagnostic or calibration use may be accumulated: examples include histograms of strip hits to identify bad strips, histograms of Photo Multiplier Tube (PMT) output to identify bad PMTs, and statistics on ACD tile response.

4.7.2 GBM Data Processing

The GBM data will be processed at the GBM IOC. The standard products include burst data, background data and catalogs. The MOC will operate GBM provided software used to refine the position of a gamma ray bursts reported via a burst alert using data sent through the TDRSS link.

4.7.3 Processing at the SSC

The SSC provides the science interface to the MOC. They perform arbitration of science goals and changes to pre-planned events. As a service to the astronomical community and the general public, the SSC will generate standard higher level products, and will post the results on the SSC website. In particular, the SSC will produce periodically sky maps of the sky and regions of interest (e.g., the Galactic Center) as well as exposure sky maps. The SSC will package burst data from each instrument into a single data product.

4.8 Science Data Archiving and Distribution

The SSC will archive all data in collaboration with the High Energy Astrophysics Science Archive Research Center (HEASARC). The raw event data and higher level products will be archived. The IOCs and the MOC are responsible for protecting the data from inadvertent loss until it is archived by the SSC. The IOCs and the MOC may also store data for an extended period of time for the convenience of their operations. There will also be Italian mirror site that will receive science data.

The SSC will provide Level 1 processed data to selected investigators from the scientific community over the Internet; the instrument teams will access their own databases. The SSC will create web-based catalogs from which investigators can determine whether observations of interest have been performed. During the first year of observations (designated Phase 1), the LAT team will validate their data while GLAST surveys the sky, and the data will be available only to the instrument teams and to guest investigators whose proposals response to a NASA Research Announcement (NRA) were accepted. Phase 1 guest investigators cannot propose alterations of the sky survey.

The first year's data will be made available to the investigator community a month after the end of the first year. In subsequent years (Phase 2) the data will become public within a day after Level 1 processing begins. The topics of the selected guest investigations will be proprietary for 3 months after all the requested data have been made available; other investigators can use the same data for other studies during this 3-month period. NRAs will be released annually.

The SSC and instrument teams will define the suite of science tools for the standard analysis environment. These tools will be developed by the instrument teams with the participation of SSC scientists. The SSC will make these tools available through its website. The SSC and the LAT team will cooperate in developing photon databases (~10 GB per year) and the software to extract data from these databases. Data extracted from the photon databases will be packaged as FITS files for investigators' use at their home institution. The photon database will be updated both when new data are accumulated and when the data are reprocessed as the understanding of the instruments improves on orbit.

The SSC will provide data, status, timeline, commanding activity history, and other mission related information to the GLAST Education and Public Outreach website on a regular basis.

The GLAST Observatory will generate 1.2 TB of downlinked data per year at a 300Kbps average daily rate plus processed products for a total data volume of approximately 2 TB per year that must be archived.

4.9 Instrument Performance Monitoring

The IOCs will monitor the performance of the instruments. This function includes calibrating the instruments and generating tables to update the parameters needed for onboard processing (for example, tables of gain settings). These tables will be provided to the MOC for formatting and uplinking.

Calibration tables will also be provided to the SSC for archival purposes insofar as the tables are relevant to the processing of downlinked data.

4.10 Operations Staffing for Routine Operations

The GLAST Mission Operations Center staff will normally work during a single prime shift on weekdays only. Status of the operation will be available over the Internet, reducing the need to be on site for engineering analysis.

The SSC and the IOCs will be staffed only on prime shift for normal operations. If the automated data processing within the IOCs has a significant problem, the system may page an on call IOC person during off-hours. If a significant instrument problem were detected during off-hours, the MOC automated systems should initiate a sequence of events in order to notify the appropriate instrument expert. The Project Scientist or a designee will be on call for target of opportunity decisions.

5 Special Operations

This section discusses operations that happen only at specific times in the mission or that occur infrequently.

5.1 Launch and Early Orbit

Launch and Early Orbit activities will be performed by the MOC. The planning and execution of this effort will require support from the spacecraft provider and GLAST instrument teams. The goal of the activities is to verify the on-orbit performance of the spacecraft and instruments.

GLAST will use additional space/ground links during launch and early operations to monitor and checkout the GLAST. These links will include TDRSS, particularly to monitor critical activities such as solar array deployment and attitude acquisition, and additional ground station contacts.

On-orbit checkout is expected to take up to 60 days. The spacecraft subsystems will be evaluated and checked first. Subsequently, the instruments will be turned on, tested, and calibrated.

Members of the spacecraft and instrument test teams will augment the normal operations team during this phase. The operations team will be staffed around the clock for the initial checkout and then transition to a prime shift only operation by the end of this phase.

5.2 End of Mission

The GLAST mission has a goal of 10 years of operations. At the end of the mission the spacecraft will perform a controlled de-orbit maneuver. The GLAST data archive will be transferred to the HEASARC for permanent archiving at the end of the mission.

5.3 Anomalies

Anomalies could range from odd housekeeping telemetry parameters to hard failures of onboard components. The instruments and the spacecraft will protect themselves from hazardous events onboard by detecting critical parameters out of limits (e.g., battery depth of discharge or instrument high voltage power supply current) and transitioning to a low power or safe mode. The spacecraft Safe Mode will be designed to keep the solar arrays pointed at the sun. A ground command will be required to return to normal operations from the Safe Mode. On the ground, significant anomalies will be identified and flagged by the automated spacecraft and instrument monitoring systems. The instrument and spacecraft engineers will find more subtle problems as they review the status data. Experts on the instruments and spacecraft will be available throughout the mission to assist in the analysis and recovery from anomalies. The instrument and spacecraft monitoring systems will be able to export status information to the Internet, to allow remote experts to access and manipulate the information. The spacecraft and instrument engineers will work with these experts to understand the problems and identify fixes and work-arounds. The TDRSS Demand Access Service that is used for burst alerts will also be used to notify the ground of problems detected onboard the observatory. TDRSS SA or MA forward link service will be used by the MOC to monitor and perform the recovery operations.

The Safe mode should be capable of protecting the health and safety of the spacecraft for an indefinite period of time, due to a single failure. The operations team will want to recover from Safe Mode quickly, to return GLAST to productive science operations, and to preclude a second failure from impacting the safety of Safe Mode. In the event that onboard failures reduce the reliability of Safe Mode, more staffing could be required later in the mission to reduce the time to recognize the transition to safe mode and to recover from it.

5.4 Software Loads

The GBM and LAT software will need to be updated during the mission, particularly early in the mission as the instrument on orbit performance is evaluated. These large loads (over 1 Mbyte) would take an extended period of time if they were done using ground stations. TDRSS will be used for these large, infrequent loads. TDRSS provides larger bandwidths and longer contact times to allow these loads to be performed.

5.5 LAT Raw Data Mode

The LAT has a mode where it will not filter events. This mode may be used to verify proper operation of the onboard software. It will be used very infrequently. In this mode, the instrument will generate large volumes of data (up to 32 Mbps). The raw data will be delivered to the IOC for processing and evaluation. The MOC may schedule an additional ground station contact to recover this data. Normal operations will be suspended if the onboard recorders fill up prior to dumping this data to the ground.

Appendix A – Observatory Operational Modes

Observatory Operational Modes

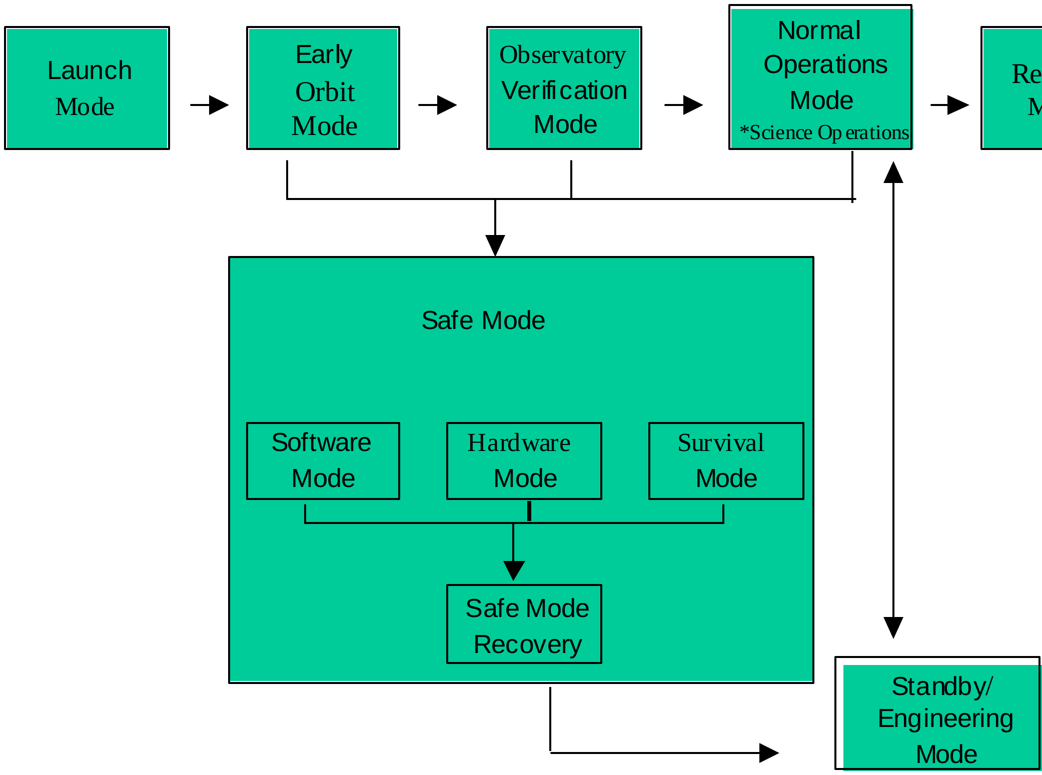

Figure 2 – Operational Modes

Introduction

This section gives definition to GLAST modes of operation. Currently there are seven observatory operational system modes planned for the spacecraft during this mission, as illustrated in Figure 2. The modes are Launch, Early Orbit, Observatory Verification, Safe, Standby/Engineering, Normal Operations (which includes Science Operations) and Reentry. Table 1 defines and gives some activities involved in each. Also included in this section are operating modes of the LAT and GBM instruments and descriptions of the observatory science operation modes: Sky Survey, Pointed Observation, Repointed Observation, and Autonomous Repointing.

- Except for Safe and Autonomous Repointing, the transitions between modes are commanded, either from the ground or from on-board stored commands.
- The operational modes have an autonomous transition to safe mode for faults that are uncorrectable by the on board system.
- Ground initiated Target of Opportunity repointings are commanded from either sky survey mode or pointed observation mode with a commanded return.

- Any repointing that is necessary for downlink transmissions in pointed mode is performed in advance by ground command. Note: If any pointing of the spacecraft becomes necessary for downlinks in survey mode, these need to be addressed with respect to how the pointing will be accomplished.

Table 1: Observatory Operational Modes Descriptions

System Modes	Activities
1. Launch Mode	This mode identifies activities that occur during launch of spacecraft
Launch Spacecraft Configuration	Spacecraft systems configured for launch
2. Early Orbit Mode	Orbit insertion, orbit determination, attitude determination
3. Observatory Verification Mode	This mode identifies activities that occur during observatory checkout
Engineering Checkout	Spacecraft subsystem checks, Guidance navigation and control calibration
Science Instrument Calibration	LAT and GBM calibrations
4. Safe Mode	This mode identifies major problem(s) onboard spacecraft and allows for troubleshooting of the problem(s). Action dependent on limit violation All safe modes include: • Orient solar arrays normal to incident sunlight • Space-ground communications are via the observatory Omni antenna, through TDRSS, with full-orbit coverage • Telemetry limited to relatively low rate (1 kbps) housekeeping data
Software Safe Mode	• Command & Data Handling: implements Safe mode subroutines
Hardware Safe Mode	• Command & Data Handling Backup (side B) or Safe Mode Computer: implements Safe Mode subroutines
Survival Mode	• All non-essential loads off, survival heaters on, spacecraft safe attitude
Safe Mode Recovery	• Execute commands to troubleshoot and bring spacecraft back to Standby Engineering Mode
5. Standby/Engineering Mode	This mode is an transition mode before normal/science mission operations providing engineering and science housekeeping telemetry • X-band communication (more data can be downloaded) or S-Band as needed • Checkout of instrument(s) • New software uploads • Raw data downlinks
6. Re-entry Mode	This mode identifies activities required for safe disposal of spacecraft as it is returned to earth at the end of the GLAST mission • Guidance and Navigation Control (GNC) subsystem and propulsion subsystem will be commanded by ground system to bring the observatory down through the atmosphere to the disposal area • Space-ground communications will be through TDRSS with full-orbit coverage • Payload instruments are powered off and the spacecraft propulsion is activated
7. Normal Operations Mode	This mode identifies the day to day mission operations activities • Commanding the observatory • Monitor observatory health and safety • Mission scheduling • Orbit predictions • Data Distribution • Alert message routing • Trend Analysis
Science Operations Mode	Gather instrument science data • Sky Survey

	• Pointed Observation • Repointed Observation • Burst data

A.1 Science Observation Modes

The modes listed below are the science observation modes of the observatory.

A.1.1 Sky Survey Mode

Sky survey mode is basically zenith pointed throughout the orbit and has two rocking profiles: 1) with rocking, and 2) without rocking. Rocking provides for more uniform sky coverage and allows for complete sky coverage within a shorter period of time. Different rocking profiles may be implemented, (square, sinusoid) with a basic 2-orbit period and a 60-degree maximum amplitude (above and below the orbit plane). Observations are uninterrupted by downlink transmission of science data in this mode.

A.1.2 Pointed Observation Mode

In Pointed Observation mode, the Z-axis of the observatory is pointed to a commanded celestial target. An observing sequence is implemented via a series of commanded targets. Earth avoidance is accomplished in this mode via stored commands that keep the field of view on the sky while the target is occulted. Alternatively, an automatic earth avoidance capability may be used, as will be described below.

A.1.3 Repointed Observation Mode

This mode is used to implement the observation of Targets of Opportunity that are identified by ground personnel. Repointed observations are those that interrupt either scanning or in-progress pointed observations. In the basic command driven system, such interruptions would occur only for TOOs in which a repointing command is up linked in real time. A repoint command would be uplinked via TDRSS. Responsibility for commanding is entirely ground based and is therefore unconditional on board. There is no commandable “enable” implemented on board and no check is made to see if the time for a downlink transmission is imminent. Earth avoidance during target occultations may be implemented via stored command upload at the option of the ground. The selection of a secondary target during an occultation of a primary target is also a ground system responsibility. The duration of a repointing, which may last through several target occultations, may be a command parameter, or it may be determined by a follow-up ground command that returns the spacecraft to the previously interrupted mode.

A.1.4 Autonomous Repointing Mode

In Autonomous Repointing Mode, the spacecraft responds to repoint commands that are received from the LAT instrument. The LAT instrument evaluates gamma-ray bursts that are detected by itself and/or by the GBM and decides its own response and whether to issue a repoint command. These commands can occur while the observatory is in sky survey mode or pointed observation mode. Upon receipt of a repoint command the spacecraft would bookmark the activity (scanning with/without rocking profile or target tracking sub mode with elapsed time on target). The spacecraft would also transition to repoint mode to evaluate the repoint command against a ground enable command or a downlink transmission of imminent science data, both are conditions for repointing.

It is not necessary to check the location of the repoint target and whether an occultation is imminent if there is an Earth avoidance capability or the determination that repointing need not avoid the Earth. The latter would maximize the observation time for a transient target. If the above conditions are not met, the observatory will revert to its previous mode. This includes a notification to the LAT that the repointing was not performed.

The duration of an autonomous repointing is controlled by a commandable duration parameter, which will be preset (initially 5 hours). The period for a repointed observation may include a number of occultations of the target.

The Autonomous Repointing Mode also includes the capability for earth avoidance during occultation of a pointed or repointed target. Two methods of earth avoidance are available and may be used singly or in combination. For high latitude targets relative to the plane of the orbit, > 30 degrees (TBR), the LAT central field of view can be made to track the perimeter of the earth's horizon disk by maintaining the central angle between the nadir direction and the +Z axis direction.

Earth Avoidance for Pointed Observations

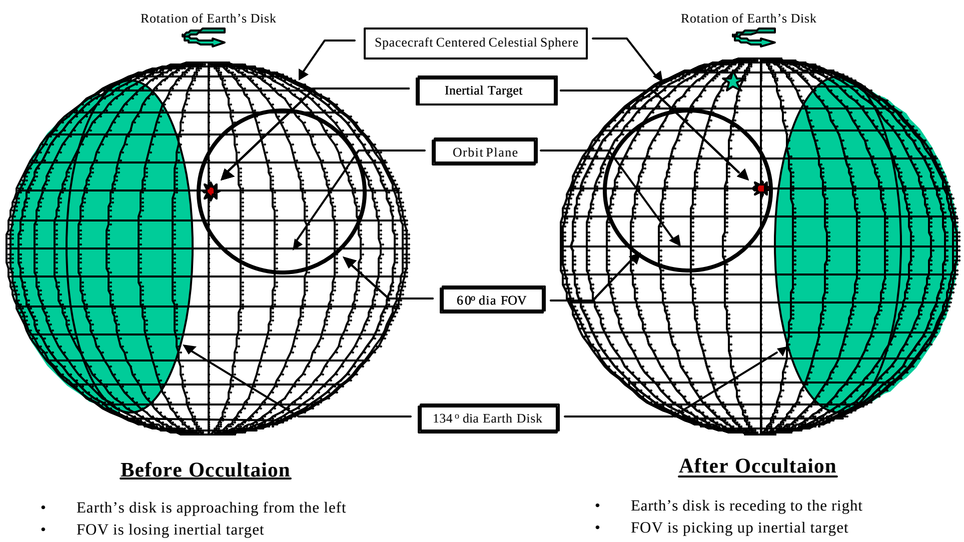

Figure 3

For low latitude targets relative to the plane of the orbit, < 30 degrees, the LAT central field of view may scan the open sky along a small circle at target latitude. While secondary targets may be used, they would not be necessary for the sake of maintaining observing efficiency.

A.2 GBM Operational Modes

A central Data Processing Unit (DPU) collects the signals from all 14 GBM detectors. This unit digitizes and time-tags the detector pulse height signals, packages the resulting data into several different types for transmission to the ground (via the GLAST spacecraft), and performs various data processing tasks such as autonomous burst triggering. In addition, the DPU is the sole means of controlling and monitoring the instrument. Included in this function is the ability to control adjustable detector power supplies to enable automatic control of the gain of each PMT.

There are three basic types of science data: (1) continuous data consist of the counting rates from each detector with various (selectable) energy and time integration bins; (2) trigger data contain lists of individually time-tagged pulse heights from selected detectors for periods before and after each on-board trigger event; (3) burst alert data contain computed data from a burst trigger, such as intensity, location, and classification. The burst alert data receives priority telemetry that allows transmission to the ground at any time in less than 7 seconds. Alerts are also made available to the LAT and to the spacecraft to aide in LAT burst detection and for making re-pointing decisions. The remaining data types are transmitted via discrete ground contacts with a typical latency of <12 hours. The algorithm for autonomous burst triggering is TBD.

The main GBM operating modes, continuous and burst trigger, correspond to the type of data being collected and transmitted. Additional modes are used in response to anomalies:

A.2.1 Continuous

This is the normal operating mode of the instrument. All instrument voltages are on and the continuous data types (Continuous high energy resolution data type (*CSPEC),* Continuous high time resolution data type (*CTIME),* Continuous housekeeping data type (*CHK)*) are being acquired and transmitted.

A.2.2 Burst trigger

Enabled upon command from the autonomous burst trigger software, or by direct command from the spacecraft. In addition to the continuous data types, the trigger data types (Time-tagged Event *(TTE),* Trigger data type *(TRIGDAT)*) are also acquired and transmitted. Instrument voltages are unaffected. The instrument returns autonomously to continuous mode under software control.

A.2.3 Diagnostic

Enabled and disabled upon direct command from the spacecraft. The details of this mode are TBD. Some instrument voltages may be turned off or adjusted, and mode-specific data types may be acquired and transmitted in addition to some combination of continuous and trigger data types. This mode is used infrequently in response to anomalies, and possibly during the initial on-orbit checkout.

A.2.4 Safe

Enabled and disabled upon direct command from the spacecraft. The details of this mode are TBD. Some instrument voltages may be turned off or adjusted.

A.2.5 SAA
Enabled and disabled upon direct (stored) command from the spacecraft. Detector high voltages are turned off. If entered from continuous mode, only *CHK* data are acquired and transmitted. If entered from burst trigger mode, pre-trigger *TTE* data may also be transmitted.

A.3 LAT Operational Modes
The LAT modes correspond to changes in instrument or observatory configuration, which significantly modify the state of the LAT instrument. These changes include transitions during the LAT power up sequence and transition into Safe Mode. The instrument will be protected when the spacecraft traverses the South Atlantic Anomaly (SAA). This will occur about 15% of the time. Calibration and engineering activities that impact LAT science observation efficiency also qualify as instrument modes.

A.3.1 LAT Operating Modes

A.3.1.1 Science Observing Modes

The LAT science observing modes are to be determined.

A.3.1.2 Engineering Modes
Listed below are the LAT engineering modes

A.3.1.2.1 Standby

All subsystems are configured and ready for transition to nominal observing.

A.3.1.2.2 Engineering

This mode is used for flight software update, parameter changes, and subsystem configuration changes.

A.3.1.2.2 Calibration

Raw L1T data downlink, other subsystem calibration modes which impact science observing

A.3.1.2.4 SAA Mode

Safing of ACD photomultiplier tubes for high ambient charged particle density environments like the south Atlantic anomaly

A.3.1.2.5 Sensors On

All sensor subsystems powered on and housekeeping active.

A.3.1.2.6 DAQ On

All nodes of LAT DAQ are powered on and configured, housekeeping active.

A.3.1.3 LAT On

The LAT Spacecraft Interface Unit (SIU) is powered on and performing thermal monitoring and local thermal control. Housekeeping systems are available for power and temperatures. All S/C interfaces are active.

A.3.1.4. Survival Mode

The LAT is powered off. The LAT is performing thermal control using survival heaters. Power for the survival heaters is provided by the S/C. This mode is also used in launch and early orbit operations.

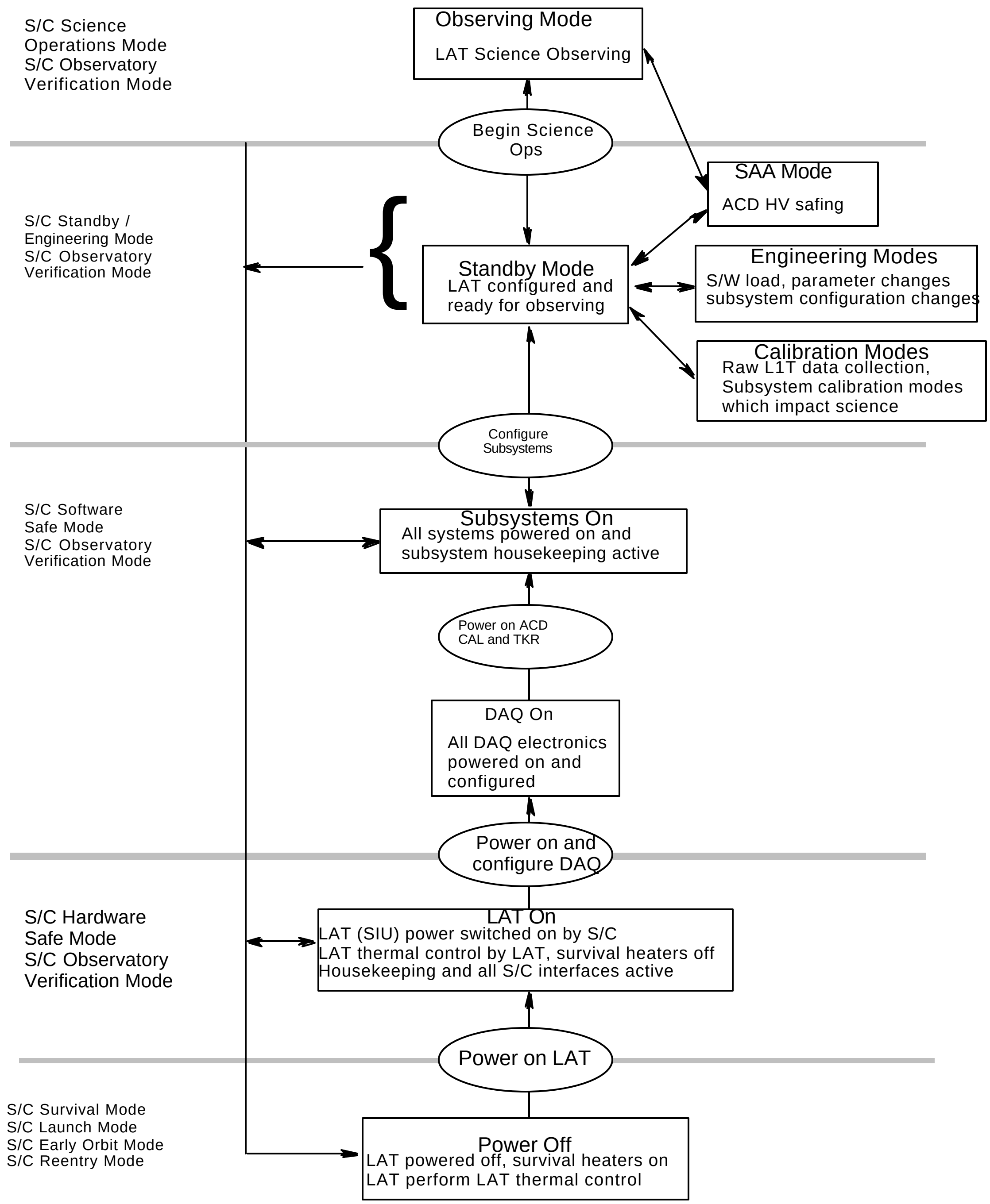

Figure 4   LAT Modes and Transitions

Table 2: Spacecraft and LAT Modes

	LAT Modes								
S/C Modes	*Power Off*	*LAT On*	*DAQ On*	*Subsystems On*	*SAA Mode*	*Calibration*	*Engineering*	*Standby*	*Observing Modes*
Launch & Early Orbit	X								
Observatory Verification		X	X	X	X	X	X	X	X
Survival Mode	X								
Hardware Safe Mode		X							
Software Safe Mode					X				
Safe Mode Recovery		X	X	X	X	X	X	X	
Standby/Engineering Mode					X	X	X	X	
Science Operations									X
Re-entry	X								

The correspondence between LAT modes and Observatory Operational modes is shown in Figure 2 and in Table 2. Spacecraft Observatory Verification Mode includes all LAT modes except powered off. All LAT modes are verified during observatory verification, including the power up sequence. LAT submodes exist for all powered LAT modes depending on the configuration of LAT to spacecraft interfaces as prime or redundant. The operational status of LAT subsystems for the various spacecraft safe modes is TBR.

The LAT flight software will be monitoring LAT power, thermal, and spacecraft C&DH interface status. Out-of-limits conditions may trigger actions resulting in LAT mode transitions and a request for the spacecraft to dispatch a health and safety alert to the MOC.